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Alternative Approaches to p-type Doping of GaN

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1. The problem being addressed: P-type doping of GaN

- Conventional (column II) acceptors produce low hole concentrations.
- High hole concentrations are needed for low resistivity p-type material and p-type ohmic contacts.

2. Technical Approach: Boron doping

Background: Boron doping

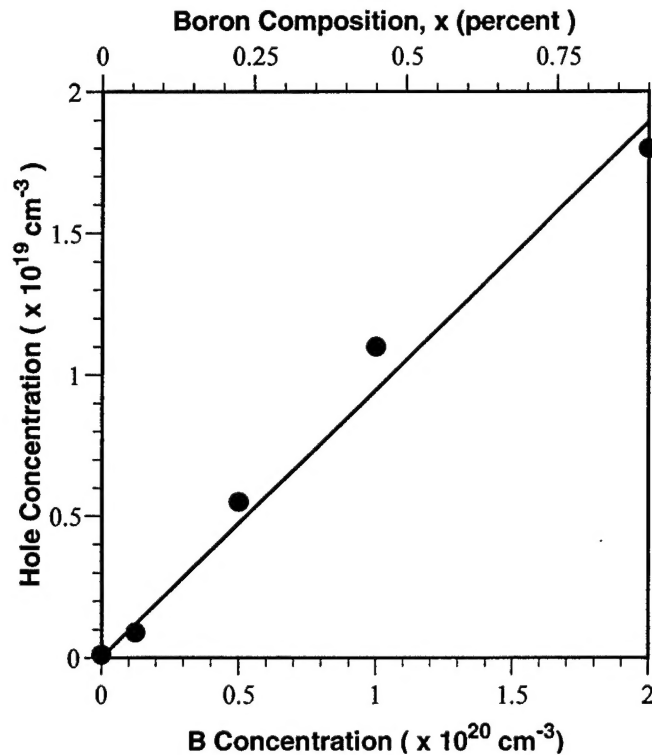
III	IV	V
B		N
Al		P
Ga		As
In		Sb

Boron Doping in GaAs

•Experimental Evidence: 2 Sites for Boron

1. B_{III} forms the ternary, B_xGa_{1-x}As. Bandgap increases with x (33 meV/%)
2. B_V is a double acceptor. Hole concentrations $> 10^{19} \text{ cm}^{-3}$ (!) are possible.

Hole Concentrations in Boron-doped GaAs



~5% of the boron atoms incorporate as B_{As}

3. Activities in this program: Boron Doping in GaN

- MBE Growth
 1. Ammonia source of nitrogen
 2. Plasma source of nitrogen
- High temperature ($<2200^{\circ}\text{C}$) Effusion Cell for Boron

Findings in the program

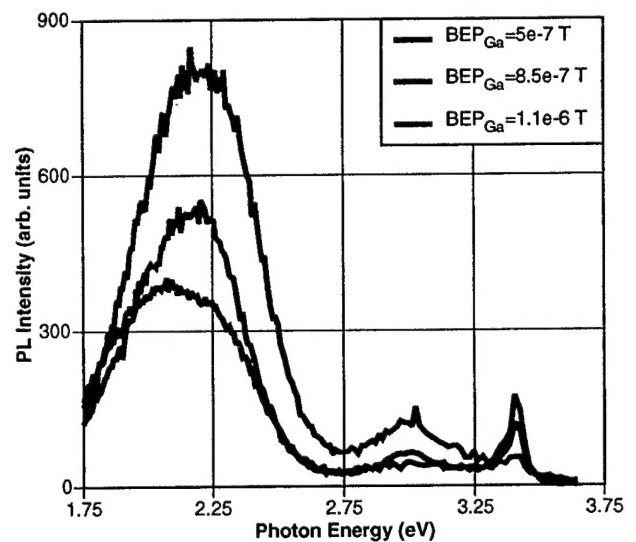
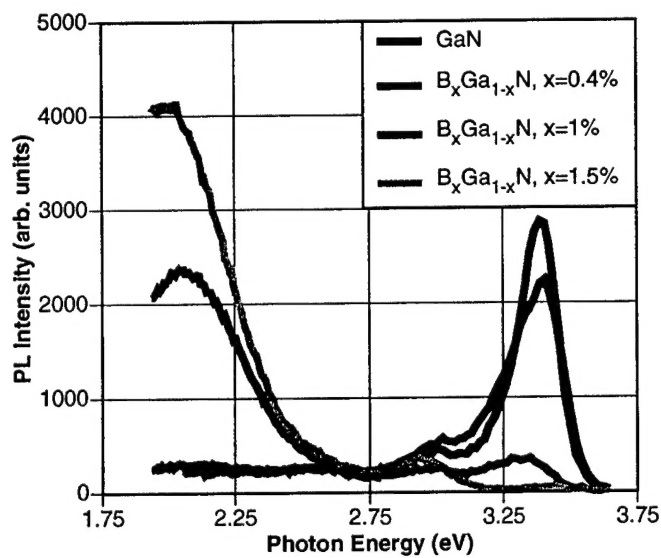
- Boron doping of GaN does *not* produce p-type conductivity.
- Boron antisite double acceptor exists in GaN, but it is too deep ($\sim 1.3 \text{ eV}$ above valence band) to produce valence band holes.

Influence of V:III Flux Ratio on Boron Site Selection (Nitrogen flux constant for all growths)

Interpretation:

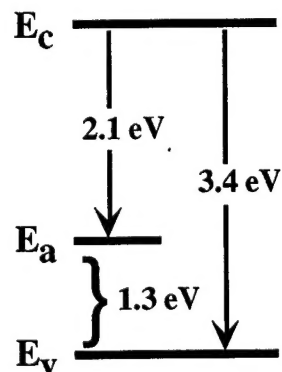
- Gallium rich growth conditions enhance the formation of B_N ; Nitrogen rich growth conditions enhance the formation of B_{Ga} .
- Increased B_N increases the compensation of the n-type background.

Room Temperature Photoluminescence of $B_xGa_{1-x}N$

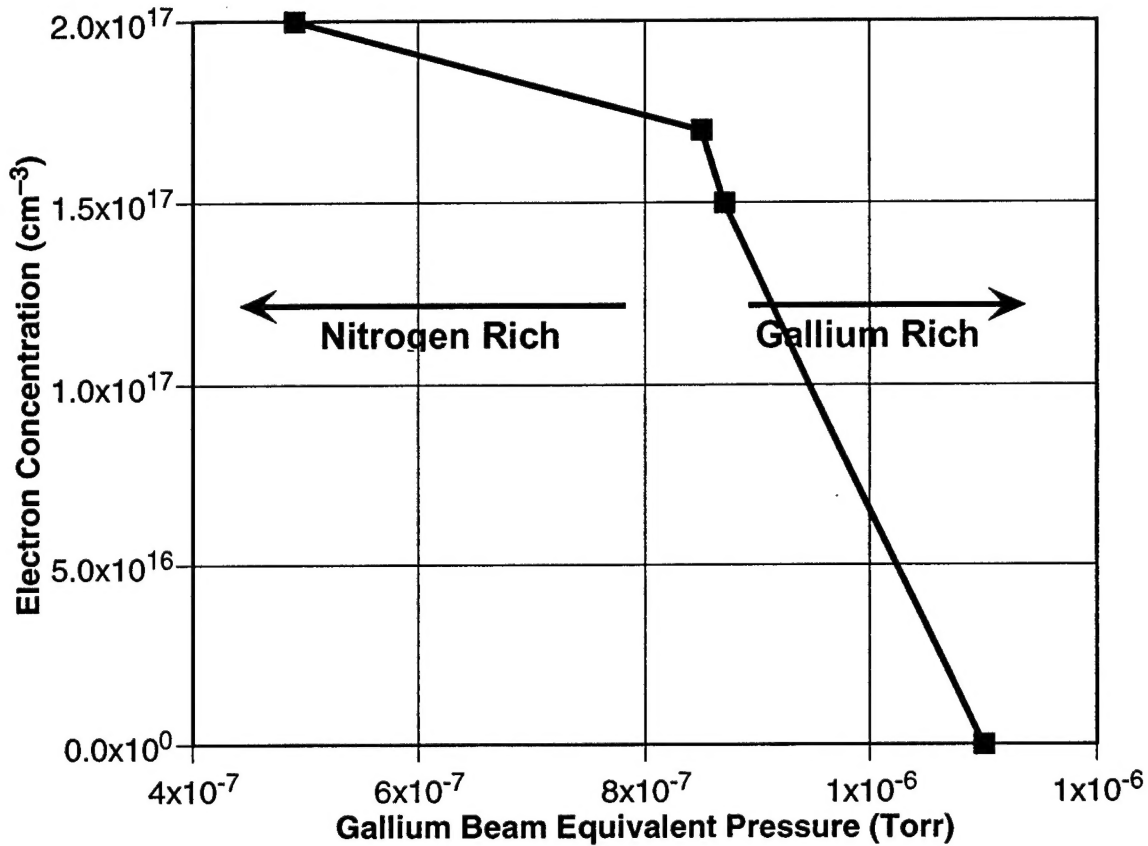


Interpretation:

Observed PL spectra are consistent with the existence of a B acceptor level around 1.3 eV above the valence band.



Evidence



- 40 GaN:B growths done (NH₃ and N-plasma sources)—no p-type GaN

- N-type conductivity ranging from:
 typical high conductivity: $n=10^{20} \text{ cm}^{-3}$ and $\mu=12 \text{ cm}^2\cdot\text{v/s}$
 to
 typical low conductivity: $n=10^{17} \text{ cm}^{-3}$ and $\mu=90 \text{ cm}^2\cdot\text{v/s}$
 to
 highly resistive

- Electron concentration in GaN:B determined by:
 ⇒unintentional donors (oxygen and nitrogen vacancies) and B_N
 ⇒affected by T_B , V/III , T_S , and outgasing

Summary: GaN:B

- B antisite double acceptor exists in GaN, but it is too deep (~1.3 eV) to be useful for producing large hole concentrations.
- The site occupancy of B is easily influenced by V/III
- The B antisite double acceptor produces strong, red PL